SULFUR

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The United States was once again the world's largest sulfur producer in 2002 with nearly 9.3 million metric tons (Mt). The sulfur was produced as byproduct of efforts to meet environmental requirements that limit the emissions of sulfur dioxide into the atmosphere. Worldwide, regulations forced increased sulfur recovery for environmental reasons and production of native sulfur and pyrites continued to decline. Because of the growth in sulfur recovery, supply continued to outpace sulfur demand, which resulted in increased stocks in some locations.

Through its major derivative, sulfuric acid, sulfur ranks as one of the most important elements used as an industrial raw material and is of prime importance to every sector of the world's fertilizer and manufacturing industries. Sulfuric acid production is the major end use for sulfur, and consumption of sulfuric acid has been regarded as one of the best indices of a nation's industrial development. More sulfuric acid is produced in the United States every year than any other chemical; 39.2 Mt, which is equivalent to about 12.8 Mt of elemental sulfur, was produced in 2002; this was slightly less than that of 2001 (U.S. Census Bureau, 2003).

In 2002, domestic production and shipments of sulfur in all forms were slightly lower than those of 2001; consumption, imports, and prices increased (table 1; figures 1-4). The United States maintained its position as the leading world consumer of sulfur and sulfuric acid. The quantity of sulfur recovered during the refining of petroleum continued the upward trend established in 1939, the second year that such production was reported, by increasing by 4.1%. Sulfur recovered from natural gas processing decreased by 12%.

Byproduct sulfuric acid from the Nation's nonferrous smelters and roasters, produced as a result of laws restricting sulfur dioxide emissions, supplied a significant quantity of sulfuric acid to the domestic merchant (commercial) acid market. Production from this sector decreased by 21%. One copper smelter closed in January, leaving three in operation. The three copper smelters that closed in 1999 did not reopen, and one zinc smelter was closed for 3 months, while another operated below capacity. In addition, production was down at lead and molybdenum operations.

Estimated world sulfur production was the same in 2002 as it was in 2001 (table 1). Frasch production in Poland continued to decline. Recovered elemental sulfur is produced primarily during the processing of natural gas and crude petroleum. About 95% of the world's elemental sulfur production came from recovered sources, which was virtually the same as the percentage reported in 2001. Some sources of byproduct sulfur are unspecified, which means that the material could be elemental or byproduct sulfuric acid. The quantity of sulfur produced from recovered sources was dependent on the world demand for fuels, nonferrous metals, and petroleum products, not for sulfur.

World sulfur consumption remained about the same as it was in 2001; about 50% was used in fertilizer production, and the remainder, in myriad other industrial uses. World trade of elemental sulfur increased by 14% from the levels recorded in 2001. Worldwide inventories of elemental sulfur were higher (International Fertilizer Industry Association, 2003).

Legislation and Government Programs

Early in 2000, the U.S. Environmental Protection Agency (EPA) issued the final rule for reduced sulfur content of gasoline, as part of tier 2 of the 1990 Clean Air Act Amendments. The standards were nationwide with the implementation time extended for some States and for some refining facilities. By 2006, the sulfur content in gasoline must average 30 parts per million (ppm) with an upper limit of 80 ppm. States in the Rocky Mountain region and Alaska were given until 2007 to reach these standards because those States generally had better air quality than other States. Small refineries with fewer than 1,500 employees or less than 155,000-barrel-per-day (bbl/d) processing capacity were not required to meet interim goals until 2008 when the national limits are to be imposed. The 2008 deadline could be delayed until 2010 if the refiners could demonstrate a severe economic hardship. Small refineries received special consideration because the installation of new equipment in small facilities could be economically damaging (Oil & Gas Journal, 2000b).

In 2002, two refineries applied to the EPA for more time to meet new sulfur-content regulations for fuels. Two other refineries had been granted extensions in 2001 (North American Sulphur Service, 2002). Two refineries closed rather than incur the costs of upgrading to meet new specifications, and another company was seeking a buyer for its refinery rather than incur the costs of an upgrade (Sulphur, 2001d; Nakamura, 2002).

In December 2000, new sulfur standards for diesel fuel reduced the allowable content to 15 ppm from 500 ppm; this was a 97% decrease. The EPA reduced diesel sulfur levels in a first step to clean up emissions from heavy-duty trucks and buses. In addition to reducing sulfur dioxide emissions from diesel engines for environmental reasons, further changes were made because the new emission control apparatus needed to reduce particulate emissions from these vehicles could not operate effectively unless sulfur levels in the fuel were significantly reduced. The agency estimated the cost of diesel regulations to be 4 to 5 cents per gallon (Oil & Gas Journal, 2001b).

The petroleum refining industry, however, was concerned that the cost of compliance—which they estimated to be in the range of 15 to 50 cents per gallon—might be significantly higher than the EPA estimate. Costs that high could make it economically unfeasible for some facilities to install the necessary apparatus, thus forcing closure of refining capacity as has happened in Illinois and perhaps causing shortages in supply (Chemical Market Reporter, 2001). Estimates in 2002 placed the total cost of implementing the sulfur rules for gasoline and diesel between $11 billion and $18 billion (Cunningham, 2002b). Low-sulfur diesel presented more technological challenges than low-sulfur gasoline and required more substantial investments for high-pressure hydrotreating facilities; the sulfur compounds found in diesel are more difficult to remove than those found in gasoline (Moyse, 2000). Refineries had several options for reducing sulfur levels to meet new regulations. The least expensive choice was using advanced catalysts in desulfurization units (Garritsen and others, 2000). Other treatment options included ammonia conversion, biodesulfurization, catalytic distillation, selective absorption, and solvent extraction.

Concerns remained about how the regulations addressed the issues of timing and transportation. The required timeframe for implementing the new diesel regulations was approximately the same as that for gasoline. Questions were raised as to whether the refining industry would be able to make the required upgrades to diesel and gasoline facilities simultaneously without compromising the availability of either product. In the time period immediately preceding the implementation of new sulfur rules, engineering and contracting firms may not have the capabilities to meet all the refiners' demands. In addition, most diesel fuel is transported via pipelines that also transport home heating oil for which no new sulfur requirements were enacted. The distribution system presents significant concerns with regard to the ability of producers to deliver fuels that meet specification. Because the same pipelines are used to transport fuels of varying quality, contamination of low-sulfur fuels will be difficult to avoid (Cunningham, 2002b).

The EPA was working on new emission standards for large ocean-going vessels. Ships sailing close to shore in places like the Gulf of Mexico and the English Channel are contributing to onshore pollution. Traditionally, the Maritime Pollution Convention (Marpol) sets standards for shipping emissions and the allowable sulfur content of marine fuels, but the EPA intended to impose standards for ships in U.S. waters if Marpol did not act (Sulphur, 2001b).

Production

Elemental Sulfur.—Production statistics were collected on a monthly basis and published in the U.S. Geological Survey (USGS) monthly sulfur Mineral Industry Surveys. All of the 108 operations to which survey requests were sent responded; this represented 100% of the total production shown in table 1. In 2002, production was virtually the same as that of 2001. Shipments were the same, but the value of shipments increased by 19% owing to a similar increase in the average unit value of elemental sulfur. Trends in sulfur production are shown in figures 1 and 3.

Frasch.—Until 2000, native sulfur associated with the caprock of salt domes and in sedimentary deposits in the United States was mined by the Frasch hot-water method in which the native sulfur was melted underground with super-heated water and brought to the surface by compressed air. Freeport-McMoRan Sulphur Inc. (a subsidiary of McMoRan Exploration Co.) closed the last domestic Frasch mine, Main Pass, in 2000 (Fertilizer Markets, 2000). After extended negotiations and considerations, Freeport sold its sulfur logistics assets to Gulf Sulphur Services Ltd., LLP (a joint venture between IMC Global Inc. and Savage Industries Inc.) in 2002. Facilities for forming, loading, remelting, storing, and transporting sulfur in Galveston, TX, and Tampa, FL, and commercial contracts associated with the sulfur-handling business were included in the sale. The venture will be operated by Savage Industries (McMoRan Exploration Co., 2002).

Recovered.—Recovered elemental sulfur, which is a nondiscretionary byproduct from petroleum-refining, natural-gas-processing, and coking plants, was produced primarily to comply with environmental regulations that were applicable directly to emissions from the processing facility or indirectly by restricting the sulfur content of the fuels sold or used by the facility. Recovered sulfur was produced by 39 companies at 109 plants in 26 States and 1 plant in the U.S. Virgin Islands. Most of these plants were small with only 31 reporting production that exceeded 100,000 metric tons per year (t/yr). By source, 79% of recovered elemental sulfur production came from petroleum refineries or satellite plants that treated refinery gases and coking plants, and the remainder was produced at natural-gas treatment plants.

During the past 5 years, mergers and acquisitions contributed to the expanding dominance of large companies in the industry. The largest recovered sulfur producers, all with more than 500,000 metric tons (t) of sulfur production, in descending order of production, were ExxonMobil Corp., BP p.l.c., ConocoPhillips Co., ChevronTexaco Corp., Shell Oil Co. (including its joint-venture and subsidiary operations), Valero Energy Corp., and CITGO Petroleum Corp. (including its joint-venture refinery). The 58 plants owned by these companies accounted for 75% of recovered sulfur output during the year. Recovered sulfur production by State and region is listed in tables 2 and 3.

Five of the world's 17 largest refineries with capacity of at least 400,000 bbl/d are in the United States. They are, in decreasing order of production, Hovensa LLC's St. Croix, VI, refinery; ExxonMobil's Baytown, TX, and Baton Rouge, LA, refineries; and BP's Texas City, TX, and Whiting, IN, refineries (Nakamura, 2002). Refining capacity does not necessarily mean that these refineries were the largest producers of refinery sulfur. Sulfur production depends on installed sulfur recovery capacity as well as the types of crude that are refined at the specific refineries. Large refineries that process low-sulfur crudes may have relatively low sulfur production.

In recent years, consolidation in the petroleum industry has reduced the number of companies that operate sulfur recovery operations, although the number of sulfur plants has remained about the same. Most mergers were undertaken to improve the competitiveness of the involved companies with other giant oil corporations (Hoffman, 2000). In 1998, Amoco Co. and British Petroleum Co., p.l.c. merged to form BP Amoco p.l.c. (BP Amoco p.l.c., 1999). In 1999, Exxon Corp. and Mobil Corp. merged to form ExxonMobil (Chang, 1999). In 2000, BP Amoco p.l.c. merged with Atlantic Richfield Co. (ARCO) to form BP Amoco ARCO p.l.c.; the company name later was simplified to BP p.l.c. (Oil & Gas Journal, 2000a).

In 2001, Chevron Corp. and Texaco Inc. merged to create ChevronTexaco Corp. (Oil & Gas Journal, 2001a). Valero and Ultramar Diamond Shamrock Corp. merged, and the combined company retained the name Valero Energy Corp. (Valero Energy Corp., 2001).

Phillips purchased Tosco Corp. in 2001. After the completion of the Tosco purchase, Conoco Inc. and Phillips signed a merger agreement to create ConocoPhillips. The merger was completed in August 2002, making ConocoPhillips the third-largest integrated energy company in the United States (Phillips Petroleum Co., 2001, 2002).

Mergers also took place in the natural gas industry. In 2000, Duke Energy Corp. merged with Phillips' gas gathering, processing, and marketing unit to form Duke Energy Field Services, LLC [Duke Energy (70%) and Phillips (30%)] (Duke Energy Corp., 2001, p. 12). El Paso Energy Corp. acquired The Coastal Corp. and renamed the company El Paso Corp. (El Paso Corp., 2001; El Paso Energy Corp., 2001).

Premcor Refining Group Inc. completed the upgrade of its Port Arthur, TX, refinery to handle more heavy crude. New sulfur recovery capacity was being installed to increase production to more than 200,000 t/yr from 130,000 t/yr (Papon and Parekh, 2002). Several other refining companies were in the process of upgrading their facilities to produce low sulfur fuels from higher sulfur crude oil, most of which were not completed in 2002. ExxonMobil was building a 40,000-bbl/d coker at its Baytown refinery to handle 530,000 bbl/d of Mexican sour crude from Petróleos Mexicano S.A. de C.V. (Pemex). The upgrades were designed to increase the quality of the fuels produced at Baytown. Sulfur production at the plant was likely to increase to between 350,000 t/yr and 360,000 t/yr from about 300,000 t/yr (North American Sulphur Service, 2000). Marathon Ashland Petroleum LLC was upgrading and adding sulfur recovery capacity at its Garyville, LA, refinery to handle imports from Pemex (Cunningham, 1999).

Byproduct Sulfuric Acid.—Sulfuric acid production at copper, lead, molybdenum, and zinc roasters and smelters accounted for about 8% of the total domestic production of sulfur in all forms; this was a decrease compared with that of 2001 (table 4). One copper smelter closed early in the year, leaving three acid plants operating in conjunction with copper smelters, and six were accessories to lead, molybdenum, and zinc smelting and roasting operations. Even with the cutbacks at copper smelters, the three largest acid plants were associated with copper mines and accounted for 90% of the output. The largest copper producers—ASARCO Incorporated, Kennecott Utah Copper Corp., and Phelps Dodge Corp.—operated a total of four sulfuric acid plants at primary copper smelters.

Total domestic byproduct acid production decreased by 21% from that of 2001. Acid from copper smelters decreased by 14% because of the closure of a smelter. One zinc producer also closed its smelter for major repairs and another was operating below capacity for several months. The closures resulted from a serious slump in the world copper and zinc industries that led to low copper and zinc prices. Byproduct acid production at lead, molybdenum, and zinc smelters was 54% lower than in 2002.

Consumption

Apparent domestic consumption of sulfur in all forms was 5% higher than that of 2001 (table 5). Of the sulfur consumed, 75% was obtained from domestic sources—elemental sulfur (68%) and byproduct acid (7%)—compared with 80% in 2001 and 78% in 2000. The remaining 25% was supplied by imports of recovered elemental sulfur (22%) and sulfuric acid (3%). The USGS collected end-use data on sulfur and sulfuric acid according to the standard industrial classification of industrial activities (table 6).

Sulfur differs from most other major mineral commodities in that its primary use is as a chemical reagent rather than as a component of a finished product. This use generally requires that it be converted to an intermediate chemical product prior to its initial use by industry. The largest sulfur end use, sulfuric acid, represented 68% of reported consumption with an identified end use. Some identified sulfur end uses were tabulated in the "Unidentified" category because these data were proprietary. Data collected from companies that did not identify shipment by end use also were tabulated as "Unidentified." A significant portion of the sulfur in the "Unidentified" category may have been shipped to sulfuric acid producers or exported, although data to support such an assumption were not available.

Because of its desirable properties, sulfuric acid retained its position as the most universally used mineral acid and the most produced and consumed inorganic chemical, by volume. Although apparent consumption increased by 5% in 2002, data based on USGS surveys of sulfur and sulfuric acid producers showed that reported U.S. consumption of sulfur in sulfuric acid (100% basis) decreased by 6%, and total sulfur consumption was 9% lower than that of 2001. These discrepancies may be attributed to inaccuracies in reporting in 2001 and 2002.

Agriculture was the largest sulfur-consuming industry; consumption in that end use increased to 9.0 Mt compared with 8.2 Mt in 2001, creating additional demand for elemental sulfur. The sulfur industry, however, had changed with the cessation of Frasch sulfur production, and when demand increased, there was no swing supplier to readily make up the difference. The phosphate industry experienced shortages in sulfur supply, and some producers were unable to operate at intended levels (d'Aquin, 2002b). Reported consumption of sulfur in the production of phosphatic fertilizers was 5% higher than that of 2001; this was a result of increased production at phosphoric acid plants. According to export data from the U.S. Census Bureau (2003), the estimated quantity of sulfur needed to manufacture exported phosphatic fertilizers decreased by 4% to 5.0 Mt.

The second largest end use for sulfur was in petroleum refining and other petroleum and coal products. Producers of sulfur and sulfuric acid reported a slight decrease in the consumption of sulfur in that end use. Demand for sulfuric acid in copper ore leaching, which was the third largest end use, decreased 15% as a result of lower copper production from leaching operations.

The U.S. Census Bureau (2003) also reported that 2.53 Mt of sulfuric acid was produced as a result of recycling spent and contaminated acid from petroleum alkylation and other processes. Two types of companies recycle this material—companies that produce acid for consumption in their own operations and also recycle their own spent acid and companies that provide acid regeneration services to sulfuric acid users. The petroleum refining industry was believed to be the largest source and consumer of recycled acid for use in its alkylation process.

Stocks

Yearend inventories held by recovered elemental sulfur producers decreased to 181,000 t, or about 22% less than that of 2001 (table 1). Based on apparent consumption of all forms of sulfur, combined yearend stocks amounted to about a 6-day supply, compared with an 8-day supply in 2001, a 6-day supply in 2000, a 12-day supply in 1999, and a 7-day supply in 1998. In 2002, yearend stocks were the lowest they had been since Frasch production became profitable early in the 20th century (Haynes, 1959, p. 61). Final stocks in 2002 represented 3% of the quantity held in inventories at the end of 1976 when sulfur stocks peaked at 5.65 Mt; this was a 7.4-month supply at that time (Shelton, 1978, p. 1296). In most cases, recovered sulfur producers found it difficult to accumulate any significant stockpiles. Many operations that recover sulfur did not have sufficient space for storing excess sulfur, and in many locations, environmental regulations did not allow stockpiling. Without Frasch production, domestic sulfur stocks were expected to remain relatively stable.

Prices

The contract prices for elemental sulfur at terminals in Tampa, FL, which are reported weekly in Green Markets, began the year at $31 to $34 per metric ton. They rose throughout the year. By the end of January, prices increased to $39 to $42 per ton and remained there until April when they rose to $43 to $46 per ton. Contract prices rose in August to $49 to $52 per ton. In November, prices increased again and remained at $56.50 to $59.50 per ton through yearend.

Based on total shipments and value reported to the USGS, the average value of shipments for all elemental sulfur was estimated to be $11.84 per ton, which was 18% higher than that of 2001. Prices varied greatly on a regional basis, which caused the price discrepancies between Green Markets and USGS data. Tampa prices were usually the highest reported because of the large sulfur demand in the central Florida area. U.S. west coast prices were listed at $0 per ton, although, in reality, west coast producers can often face negative values as a result of costs incurred at forming plants. These costs were necessary to make solid sulfur in acceptable forms, often known as prills, to be shipped overseas. The majority of west coast sulfur was sent to prillers who may have been subsidized by the refineries, and the formed sulfur was shipped overseas (Green Markets, 1999).

Foreign Trade

Exports of elemental sulfur from the United States, which included the U.S. Virgin Islands, as listed in table 7, were slightly higher in quantity than those of 2001 and 18% lower in value because the average unit value of U.S. export material decreased to $58.24 per ton. Exports from the west coast were 577,000 t, or 84% of total U.S. exports.

The United States continued to be a net importer of sulfur. Imports of elemental sulfur exceeded exports by almost 2 Mt. Recovered elemental sulfur from Canada and Mexico delivered to U.S. terminals and consumers in the liquid phase furnished about 93% of all U.S. sulfur import requirements. Total elemental sulfur imports increased by about 48% in quantity and by 22% in value; imports from Canada, mostly by rail, were 62% higher in quantity, and waterborne shipments from Mexico were 20% higher than those of 2001 (table 9). Imports from Venezuela were estimated to account for about 7% of all imported sulfur.

As a result of volatile prices and tight supplies, several Florida fertilizer companies continued to pursue necessary permits to build a terminal south of Tampa to handle formed sulfur to avoid future supply disruptions. After several unexpected delays in late 2000 and 2001, Big Bend Transfer Station Co. (BBTC) (a joint venture of Cargill, Inc.; CF Industries, Inc.; and IMC) received approval for its sulfur melting plant south of Tampa from the Hillsborough County Commission in March 2002 with construction expected to begin in early 2003 (Green Markets, 2002; North American Sulphur Service, 2002c). The joint venture was formed to build a facility for remelting formed sulfur as a means of diversifying the companies' supply options. Upon successful completion of the permitting process, BBTC planned to install facilities for handling 1.5 million metric tons per year (Mt/yr) of sulfur with possible expansions to 2 Mt/yr (Green Markets, 2001a). This would enable BBTC to buy formed sulfur at the best prices available, perhaps from foreign producers.

In addition to elemental sulfur, the United States also had significant trade in sulfuric acid. Sulfuric acid exports were 30% lower than those of 2001 (table 8). Acid imports were seven times greater than exports (tables 8, 10). Canada and Mexico were the sources of 67% of U.S. acid imports, most of which were probably byproduct acid from smelters. Canadian and some Mexican shipments to the United States came by rail, and the remainder of imports came primarily by ship from Europe and Japan. The tonnage of sulfuric acid imports was 25% lower than that of 2001, and the value of imported sulfuric acid decreased by 10%.

World Review

The global sulfur industry remained divided into two sectors—discretionary and nondiscretionary. In the discretionary sector, the mining of sulfur or pyrites is the sole objective; this voluntary production of native sulfur or pyrites is based on the orderly mining of discrete deposits with the objective of obtaining as nearly a complete recovery of the resource as economic conditions permit. In the nondiscretionary sector, sulfur or sulfuric acid is recovered as an involuntary byproduct, the quantity of output subject to demand for the primary product irrespective of sulfur demand. Nondiscretionary sources represented 10% of the sulfur produced in all forms worldwide as listed in table 11.

Poland was the only country that produced more than 500,000 t of native sulfur by using either the Frasch or conventional mining methods (table 11). Small quantities of native sulfur were produced in Asia, Europe, and South America. The importance of pyrites to the world sulfur supply has significantly decreased; China was the only country of the top producers with more than 500,000 t of sulfur produced whose primary sulfur source was from pyrites. About 75% of world pyrites production was in China.

Of the 22 countries listed in table 11 that produced about 500,000 t or more of sulfur, 14 obtained the majority of their production as recovered elemental sulfur. These 22 countries produced 91% of the total sulfur produced worldwide. The international sulfur trade was dominated, in descending order of quantity, by Canada, Russia, Saudi Arabia, the United Arab Emirates, Germany, and Japan; these countries exported more than 1 Mt of elemental sulfur each and accounted for 78% of total sulfur trade. Major sulfur importers, in descending order, were China, Morocco, the United States, India, Brazil, and Tunisia, all with imports of more than 1 Mt.

World production of sulfur was the same in 2002 as it was in 2001; consumption was believed to be slightly higher. Production exceeded consumption in 2002 for the 11th consecutive year.

Prices in most of the world were believed to have averaged higher throughout the year than in 2001. Production of Frasch was 19% lower than that of 2001 as a result of continued declines at the last remaining mine in Poland. Recovered sulfur production was virtually the same, and byproduct sulfuric acid production increased slightly compared with those of 2001. Supplies of sulfur in all forms continued to exceed demand; worldwide sulfur inventories increased, much of which was stockpiled in Canada. Globally, production of sulfur from pyrites was about the same.

Statistics compiled by the Oil & Gas Journal showed that the United States possessed 20% of the world's total refining capacity and 42% of the world's sulfur recovery capacity derived from oil refineries. The publication listed 722 oil refineries in 119 countries; only about one-half of these countries were reported to have sulfur recovery capacity (Stell, 2002, p. 69-70). Although the sulfur recovery data appeared to be incomplete, analysis of the data showed that most of the countries that reported no sulfur recovery at refineries were small and had developing economies and limited refining industries. In general, as refining economies improve and the refining industries mature, additional efforts are made to improve sulfur recovery and atmospheric emissions.

Sulfur levels in motor fuels were being cut worldwide. The European Council speeded up the deadline for mandatory sulfur-free fuels to 2009 from 2011. At that time, 10 ppm will be the maximum quantity of sulfur allowable in gasoline and diesel for all vehicles and equipment including off-road vehicles (Sulphur, 2002a). Russia adopted regulations to limit sulfur in fuels, although the rules are not as strict as those in the European Union (EU). New legislation places the maximum sulfur content for diesel at 350 ppm and for gasoline at 150 ppm by 2004. Efforts were being made to make lower sulfur fuels available for vehicles that will be traveling in the EU to conform to regulations there (Sulphur, 2002g). Japan was working on legislation similar to that in Europe that would limit the sulfur content of diesel and gasoline to 10 ppm from current limits of 50 ppm and 500 ppm, respectively, by 2008. As in other countries, the Japanese refining industry raised concerns about the cost and timing of new requirements (Sulphur, 2002c).

The European Commission was contemplating the implementation of regional sulfur limits for fuels used to power ships sailing in the North Sea and the Baltic Sea if the International Maritime Organization, the group that regulates maritime operation, is not able to receive ratification for its new regulations from its member states. The sulfur content of ship fuel would be limited to 1.5% when sailing in territorial waters. In harbors, fuels would be limited to 0.2% sulfur. As sulfur emissions are cut from other sources, shipping is becoming an increasingly large source of sulfur dioxide pollution in Europe. Ship owners were investigating other methods of limiting sulfur emissions, including the installation of desulfurization equipment on ship stacks (Sulphur, 2002b).

Canada.—Canada was second only to the United States in production of byproduct sulfur production and sulfur in all forms. It led the world in exports of elemental sulfur and stockpiled material. The majority of the sulfur production came from natural gas plants in Alberta where yearend sulfur inventories were estimated to be 14.9 Mt (North American Sulphur Service, 2002a). Sulfur recovered from natural gas has declined in Canada for the past 2 years, and that trend is expected to continue. Recovery at refineries should increase, but the largest changes will be as a result of additional production from oil sands. Sulfur from oil sands is not all readily available to the market. Much of the production is at remote locations where market access is limited and the material has been poured to block, the term used for stockpiling sulfur (North American Sulphur Service, 2002b).

Alberta has huge deposits of oil sands with estimated reserves of 300 million barrels (Mbbl) of recoverable crude oil that contain 4% to 5% sulfur (Stevens, 1998). The oil sands resource in Alberta is larger than the proven reserves in Saudi Arabia (Pok, 2002). As traditional petroleum production in Canada declined, oil sands became a more important source of petroleum for the North American market (Cunningham, 2001). The proportion of Canadian production from oil sands was expected to increase to 21% in 2005 and 30% in 2010 from 9% in 2001 (Pok, 2002). Expansions of oil sands operations were planned by several companies, several existing oil refineries were undergoing conversions to enable the processing of bitumen from oil sands, and pipelines were being built to deliver the bitumen to the refineries from the deposits.

The possible ratification of the Kyoto Protocol put the future of many oil sands operations in doubt. Large quantities of carbon dioxide are produced in the process of upgrading bitumen. The cost of reducing carbon dioxide emissions could increase the cost of producing oil sands too much for at least some of the projects to remain economically feasible. The Province of Alberta was concerned that ratifying the Kyoto Protocol could cost the industry many billions of dollars and many jobs (Cunningham, 2002a).

Smelters in Canada faced the same problems as those in the United States; low metal prices forced the shutdown of Noranda Inc.'s copper smelter in Gaspe, Quebec. Originally planned to last for 6 months starting in April, the company later chose to make the closure permanent. Teck Cominco Ltd. curtailed production at its zinc smelter in Trail, British Columbia, from April to August (Fertilizer Week, 2002).

Kazakhstan.—The Tengiz oilfield and gasfield is the main source of current sulfur production in Kazakhstan. Located on the northeastern shore of the Caspian Sea in western Kazakhstan, Tengiz has been operated by Tengizchevroil (TCO) since 1993. The owners of TCO are ChevronTexaco (50%), Kazakhoil (Kazakhstan's national oil and gas company) (20%), ExxonMobil (25%), and LUKARCO (a joint venture between BP and Russian oil company LUKoil) (5%) (Chevron Corp., 2000). One of the world's largest oilfields, Tengiz contains high-quality oil with 0.49% sulfur and associated natural gas that contains 12.5% hydrogen sulfide (Connell and others, 2000).

Disagreements between the Government of Kazakhstan and TCO threatened further development of the Tengiz condensate-and-sour-gas field. Renegotiation of the original terms of the financial agreement between the Government and ChevronTexaco created doubts as to whether TCO would proceed with the second stage of development. In addition to the financial questions, local courts fined the company $73 million for environmental damage caused by the 6 Mt of elemental sulfur stockpiled at the site. The second stage of development included plans for reinjecting sour-gas to increase gas output from the field while limiting sulfur production to 2.5 Mt/yr. TCO was also planning export routes for sulfur formed at Tengiz. The two sides came to an agreement that allowed for continued operation at the field (Sulphur, 2003c).

Sulfur also is recovered from the Karachaganak gas-condensate field in Kazakhstan near the Russian border. Because it is close to the Russian gas processing operation in Orenberg, sour gas from Karachaganak is treated at Orenberg. No gas treatment facilities have been installed at that site in Kazakhstan (Sulfur, 2001c).

Agip Kazakhstan North Caspian Operating Co. (Agip TCO) [the multinational consortium headed by Italian Agip Petroli S.p.A.] was exploring the Kashagan field in the Caspian region of Kazakhstan and announced plans to build a gas processing plant in Karabatan to handle the very sour gas produced at Kashagan. The plant was designed to process 2.9 billion cubic meters per year of gas, recovering 900,000 t/yr of sulfur. Local environmentalists suggested that the plant should be built in a more remote location, far from the major population center of the country (Sulphur, 2002d). Agip TCO had considered the construction of an artificial island over the oil and gas field to support a gas processing plant and an oil refinery (Sulphur, 2002f).

Mexico.—Mexico was the second largest supplier of imported recovered sulfur to the United States. The majority of its sulfur is produced at petroleum refineries, and byproduct sulfuric acid is recovered at its smelters. Pemex was pursuing a program to cut emissions from its refineries to improve the air quality in Mexico by increasing the efficiency of its sulfur recovery units to more than 99%. Nine sulfur recovery units have been completed with a total capacity of 3,440 metric tons per day (t/d) (1.26 Mt/yr). The improvement process was initiated in 1996 when the North American Free Trade Agreement was ratified and new Mexican environmental laws were enacted. After evaluating existing sulfur recovery units, plans were made to replace or upgrade facilities that did not meet new guidelines. Air quality improvements were to continue (Sulphur, 2003b).

Russia.—Russia was expected produce more sulfur than it needs for the foreseeable future. Gazprom's gas processing plants in Astrakhan and Orenburg are the largest producers, totaling more than 5 Mt in 2002. Improvements at Norilsk Mining Company's nickel smelter are expected to increase byproduct sulfuric acid production to 400,000 t/yr from 60,000 t/yr by 2005 (Sulphur, 2003b). Russian exports were about 3.2 Mt in 2002, the second highest in the world. The 82% increase from the previous year was a large factor in the worldwide increase in trade caused by strong demand. Morocco and Tunisia were Russia's largest customers. Russian sulfur has displaced material from Canada and the Middle East in important markets in North Africa.

Venezuela.—Venezuela's Orinoco Basin is one of the world's largest resources of crude oil. If recent developments in refining technology had not provided the means for upgrading (improving the quality of) the crude, then it could not have been developed (Sulphur, 2000). Upgraded crude production from the Orinoco Basin could eventually result in the production of 8 Mt/yr of sulfur with about 5 Mt/yr of that being produced in Venezuela and the rest at refineries in other countries, very possibly in the United States (Cunningham, 2000). Three of the four projects planned began producing upgraded crude in 2001. The last was under development.

Additional projects were not very likely after Venezuela passed a law that may discourage international oil companies from investing in development projects at oilfields. In the law, basic royalties are 30%, and Petróleos de Venezuela, S.A. (PdVSA) is required to hold a minimum of one-half of the equity in any new venture (Sulphur, 2002e). These terms are not what foreign firms desire when considering new projects.

In December, a strike staged as a political protest in Venezuela had an impact on U.S. sulfur producers and consumers. Direct shipments of sulfur from the Port of José stopped, keeping Venezuelan sulfur out of the U.S. market. Crude oil shipments also were curtailed, preventing Venezuelan crude from reaching refineries with contracts to process that material, thus causing decreased sulfur production at some oil refineries (North American Sulphur Service, 2003). Citgo was the hardest hit because it is a subsidiary of PdVSA and relied on crude from Venezuela as its feedstock. Also affected were ConocoPhillips and ExxonMobil. PCS Phosphates in Aurora, NC, also was affected because it had long-term contracts for Venezuelan sulfur for its phosphate rock operations (North American Sulphur Service, 2003).

Current Research and Technology

Biodesulfurization.—The Shell-Paques/Thiopaq process was developed to remove hydrogen sulfide or sulfur oxides from light hydrocarbons, natural gas, refinery gas streams, and synthesis gas by using naturally occurring harmless microorganisms as catalysts. Elemental sulfur is recovered. Sulfur compounds are dissolved in an aqueous solution and then treated in the bioreactor to produce either elemental sulfur or sulfate compounds and hydrogen. Hydrogen sulfide removal is 99.99%. The bioreactor, which can be built in limited space, operates at ambient conditions, thus allowing use of noncorroding construction materials. Use of polypropylene and polyethylene pipes and valves results in long equipment life. These units require little attention from operators and no shutdowns for overhauls because all routine maintenance is possible while the unit is operating. In addition to its use in natural gas treatment and oil refining, Thiopaq can be used commercially in such industries as chemical processing, food processing, mining, pulp and paper, and wastewater. Original adaptations of the process can handle throughput of up to 45 t/d (Sulphur, 2001a).

During 2002, a biological natural gas desulfurization unit was brought online at a gas processing plant in Alberta. This is the first time the Shell-Paques biological system was installed at a gas plant. Elemental sulfur is recovered as an alternative to hydrogen sulfide emissions and continuous flaring (Sulphur, 2003a). Another company was installing a Shell-Paques system at an acid gas treatment plant at an oil refinery in Egypt. The plant is designed to produce 13 t/d of elemental sulfur (Sulphur, 2003d).

Reinjection of Hydrogen Sulfide.—Reinjection of sulfur as hydrogen sulfide into an appropriate underground reservoir was an attractive alternative in some instances at some natural gas operations but was seldom feasible at oil refineries. In acid gas reinjection from sour gas processing, the hydrogen sulfide and carbon dioxide were separated from the gas by using standard separation techniques and recompressed into a suitable injection zone. The suitability of the injection zone was influenced by its distance from the processing facility and could be a large aquifer, a depleted reservoir, or a zone that produces sour fluids. A depleted reservoir was especially attractive because its size and original pressure were already known, which made the determination of its holding capacity easier. The sour gases also could be reinjected into a producing deposit.

Reinjection was being used at many small-scale operations, especially in Canada, but it had not been demonstrated to work on a large scale. Preventing the migration of reinjected gases from the reservoir into adjacent reservoirs or aquifers or into the atmosphere through an outcrop was essential for successful implementation.

With large-scale reinjection schemes, the energy balance would be an important factor in determining its feasibility. Without the sulfur recovery plant that produces energy, which can be used elsewhere in the operation, steam production by using an external energy source, such as natural gas or electricity, was required. Using natural gas presented the unusual situation of producing carbon dioxide emissions to reinject carbon dioxide. A determination was needed of whether the environmental benefit of reinjecting carbon dioxide was canceled out by the carbon dioxide emissions produced for that reinjection (Connock, 2001).

ExxonMobil was proceeding with plans to reinject sour gas and carbon dioxide at its LaBarge operation in Wyoming. Sulfur production at LaBarge is around 400,000 t/yr, all of which the company planned to reinject when the facilities are complete. The company plans to reinject carbon dioxide along with sulfur dioxide (North American Sulphur Service, 2002e).

Sul-Flow.—When solid sulfur is unloaded from ships, the mechanical processes used to unload the sulfur create dust that presents environmental concerns. A newly patented process was developed to mitigate the problems related to the dust generated during the transfer of large quantities of bulk sulfur. The Sul-Flow is a hydraulic system that works best with formed sulfur and is not applicable for crushed and broken material. The system eliminates dust emissions, neutralizes acidity, and removes contaminants when it transfers sulfur from the ship to the storage facility. It can include biocide to prevent bacterial action if required.

In the process, sulfur is mixed with water to form a sulfur slurry of which the acidity is controlled. The slurry passes through a coarse screen to remove lumps and impurities. It then travels to a series of dewatering screens that also remove sulfur fines. The desired sulfur pellets then are transported to storage via conveyor belt.

Sul-Flow provides environmental benefits by eliminating atmospheric pollution by sulfur dust. Capital costs are reduced by eliminating much of the heavy machinery used to unload sulfur vessels. Maintenance costs may be reduced by the eliminating corrosion caused by sulfur dust and minimizing the equipment needed. The resulting product is of higher quality because it has been neutralized and protected from biotic action prior to storage. The product has minimal contaminants, and its particle size is maintained.

Sul-Flow offers cost savings in capital and operating costs than more traditional mechanical unloading systems. No environmental remediation should be required. The equipment needed to install the system is readily available and less complex than other methods for eliminating sulfur dust during unloading (d'Aquin, 2002a).

Outlook

The sulfur industry continued on a path of increased production, slow growth in consumption, higher stocks, and expanded world trade. U.S. production from petroleum refineries is expected to increase substantially in the next few years as expansions, upgrades, and new facilities at existing refineries are completed, thus enabling refiners to increase thoughput of crude oil and to process higher sulfur crudes. Production from natural gas operations has been decreasing during the past 2 years, and that trend is expected to continue. A major reason for continued decreases is the changes that are taking place at gas operations in Wyoming, the State in which about 70% of all natural gas sulfur is recovered. Of four large gas operations in the State, three are expected to experience significant decreases in production beginning in 2003. Two of the operations expect a decrease production owing to natural depletion of the deposit. One other is installing a large-scale facility for reinjecting hydrogen sulfide and carbon dioxide into the formation. The remaining natural gas operation completed expansion of its capacity in 2002. It was, however, pursuing permits to enable the disposal of all its sulfur, which could eliminate nearly 500,000 t of material from the market. In 2005, Wyoming sulfur production is predicted to be 27% lower than it was in 2002 even without disposal at the fourth operation. If that company chooses to dispose of sulfur rather than market it, material recovered from natural gas processing could become a very small part of the domestic industry (North American Sulphur Service, 2002d).

Worldwide recovered sulfur output should continue to increase. The largest increases in recovered sulfur production through 2005 should come from the Middle East's and Russia's growth in sulfur recovery from natural gas, Canada's expanded oil sands operations, and Asia's improved sulfur recovery at oil refineries (Kennedy, 2001). Refineries in developing countries should begin to improve environmental protection measures and eventually approach the environmental standards of plants in Japan, North America, and Western Europe.

Experts from the natural gas industry estimate that the world demand for natural gas will grow by 2.5% per year during the next 20 years for a total 50% increase in demand. Producing 50% more gas means recovering at least an additional 50% in sulfur from that source. Future gas production, however, is likely to come from deeper, hotter, and sourer deposits that will result in even more excess sulfur production unless more efforts are made to develop new large-scale uses for sulfur. Other alternative technologies for reinjection and long-term storage to eliminate some of the excess sulfur supply will require further investigation to handle the quantity of surplus material anticipated (Hyne, 2000).

Byproduct sulfuric acid production will remain depressed in the United States so long as the copper smelters remain idle. With the copper industry's switch to lower cost production processes and producing regions, the four idle smelters may never reopen. Worldwide, the outlook is different. Because copper production costs in many countries are lower than in the United States, acid production from those countries has not decreased as drastically, and increased production is likely. Environmental controls have been less of a concern in developing countries in the past. Many copper producers in developing and even in developed countries, however, are installing more efficient sulfuric acid plants to limit sulfur dioxide emissions at new and existing smelters. Planned and in-progress improvement projects could increase byproduct acid production significantly, although growth has been slower than previously expected.

Frasch and pyrites production, however, have little chance of significant long-term increases, although higher sulfur prices have resulted in the temporary increases in pyrites consumption. Turkey was building a pyrites-based sulfuric acid plant, and a Philippine company was considering whether to convert one of its sulfuric acid plants back to pyrites. Because of the continued growth of elemental sulfur recovery for environmental reasons rather than demand, discretionary sulfur has become increasingly less important as demonstrated by the closure of the Polish sulfur mine. Frasch sulfur has become the high-cost process for sulfur production. Pyrites, with significant direct production costs, is an even higher cost raw material for sulfuric acid production when the environmental aspects are considered. Discretionary sulfur output should show a steady decline. The decreases will be pronounced when large operations are closed outright for economic reasons, as was the case in 2000 and 2001.

Sulfur and sulfuric acid will continue to be important in agricultural and industrial applications, although consumption will be less than production. World sulfur demand for fertilizer is forecast to increase by about 2.3% per year for the next 10 years; industrial demand is predicted to grow by 2.2% per year as a result of increased demand for copper and nickel leaching.

The most important changes in sulfur consumption will be in location. Phosphate fertilizer production, where most sulfur is consumed, is projected to increase about by 2.0% per year through 2011. With new and expanding phosphate fertilizer capacity in Australia, China, and India, sulfur demand will grow in these areas at the expense of some phosphate operations elsewhere, thus transferring sulfur demand rather than creating new demand. The effects were already being felt by the U.S. phosphate industry as reflected in the permanent closure of some facilities and reduced production at others. U.S. phosphate products supply domestic requirements, but a large portion of U.S. production is exported. China and India are primary markets for U.S. phosphatic fertilizers. As the phosphate fertilizer industries develop in these countries, some of the markets for U.S. material could be lost. Sulfur will be required for phosphate production at new operations, and more producers will be competing for those markets.

Use of sulfur directly or in compounds as fertilizer should increase, but this use will be dependent on agricultural economies and increased acceptance of the need for sulfur in plant nutrition. If widespread use of plant nutrient sulfur is adopted, then sulfur consumption in that application could be significant; thus far, however, growth has been slow.

Industrial sulfur consumption has more prospects for growth than in recent years, but still not enough to consume all projected surplus production. Conversion to or increases in copper leaching by producers who require significantly more sulfuric acid for the leaching operations than was used in 2002 bode well for the sulfur industry. Nickel pressure acid leach operations were demanding increased quantities of sulfur. Changes in the preferred methods for producing oxygenated gasoline, especially in Canada and the United States, might result in additional alkylation capacity that would require additional sulfuric acid. Other industrial uses show less potential for expansion. Production is expected to surpass demand well into the future.

Unless less traditional uses for elemental sulfur increase significantly, the oversupply situation will result in tremendous stockpiles accumulating around the world. In the 1970s and 1980s, research was conducted that showed the effectiveness of sulfur in several construction uses that held the promise of consuming huge quantities of sulfur in sulfur-extended asphalt and sulfur concretes. In many instances, these materials were found to be superior to the more-traditional products, but their use so far has been very limited. Interest in these materials seemed to be increasing but only in additional research. No large-scale projects were announced that would require sizable quantities of sulfur. These proposals may have to be revisited to avoid building mountains of sulfur in the not-too-distant future.

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TABLE 1
SALIENT SULFUR STATISTICS[1]

(Thousand metric tons of sulfur content and thousand dollars unless otherwise specified)

	1998	1999	2000	2001	2002
United States:					
Production:					
Frasch	1,800 e	1,780 e	900 e	--	--
Recovered[2]	8,300 r	8,360 r	8,590 r	8,490 r	8,500
Other	1,610	1,320	1,030	982	772
Total[e]	11,700 r	11,500 r	10,500 r	9,470 r	9,270
Shipments:					
Frasch	W	W	W	--	--
Recovered[2]	10,600 r, 3	9,940 r, 3	9,710 r, 3	8,470 r	8,490
Other	1,610	1,320	1,030	982	772
Total	12,200 r	11,300 r	10,700 r	9,450 r	9,260
Exports:					
Elemental[4]	889	685	762	675	687
Sulfuric acid	51	51	62	69	48
Imports:					
Elemental	2,270	2,580	2,330	1,730	2,560
Sulfuric acid	668	447	463	462	346
Consumption, all forms[5]	14,200 r	13,800 r	12,700 r	10,900 r	11,400
Stocks, December 31, producer, Frasch and recovered	283	451	208	232	181
Value:					
Shipments, free on board (f.o.b.) mine or plant:					
Frasch	W	W	W	--	--
Recovered[2]	$308,000 r, 3	$376,000 r, 3	$240,000 r, 3	$84,700 r, e	$100,000 e
Other	$77,100	$66,400	$55,100	$49,500	$35,500
Total	$386,000 r	$442,000 r	$295,000	$134,000 r	$135,000
Exports, elemental[6]	$35,400	$35,800	$53,700	$48,800	$40,000
Imports, elemental	$58,400	$51,600	$39,400	$22,100	$26,800
Price, elemental, f.o.b. mine or plant dollars per metric ton	29.14	37.81	24.73	10.01 r, e	11.84 e
World, production, all forms (including pyrites)	57,400 r	57,400 r	58,300 r	57,700 r	57,700 e

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data; included with "Recovered." -- Zero.

[1]Data are rounded to no more than three significant digits except prices; may not add to totals shown.

[2]Includes U.S. Virgin Islands.

[3]Includes corresponding Frasch sulfur data.

[4]Includes exports from the U.S. Virgin Islands to foreign countries.

[5]Consumption is calculated as shipments minus exports plus imports.

[6]Includes value of exports from the U.S. Virgin Islands to foreign countries.

TABLE 2

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY STATE[1]

(Thousand metric tons and thousand dollars)

State	2001			2002		
		Shipments			Shipments	
	Production	Quantity	Value[e]	Production	Quantity	Value[e]
Alabama	304	301	2,240	269	271	3,880
California	963	951	2,280	965	962	3,590
Illinois	436	437	837	414	412	1,420
Louisiana	1,100	1,100	12,800	1,160	1,160	15,700
Michigan and Minnesota	35	36	176	35	34	119
Mississippi	559	551	22,200	545	547	24,900
New Mexico	49	49	(2)	43	43	(2)
North Dakota	56	56	(2)	45	45	(2)
Ohio	112	113	554	115	116	1,260
Texas	2,740	2,740	36,700	2,750	2,730	41,600
Washington	102	102	(2)	105	106	(2)
Wyoming	1,320 r	1,330 r	7,860 r	1,340	1,360	2,640
Other[3]	699	694	-927 r	717	710	5,430
Total	8,490 r	8,470 r	84,700 r	8,500	8,490	100,000

[e]Estimated. [r]Revised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Some sulfur producers in this State incur expenses to make their production available to consumers.

[3]Includes Arkansas, Colorado, Delaware, Florida, Indiana, Kansas, Kentucky, Montana, New Jersey, Pennsylvania, Utah, Virginia, Wisconsin, and the U.S. Virgin Islands.

TABLE 3

RECOVERED SULFUR PRODUCED AND SHIPPED IN THE UNITED STATES, BY PETROLEUM ADMINISTRATION FOR DEFENSE (PAD) DISTRICT[1]

(Thousand metric tons)

	2001		2002	
District and source	Production	Shipments	Production	Shipments
PAD 1:				
Petroleum and coke	187	187	233	233
Natural gas	37	37	27	27
Total	224	225	260	260
PAD 2:				
Petroleum and coke	900	902	852	850
Natural gas	58	58	48	47
Total	958	960	900	897
PAD 3:[2]				
Petroleum and coke	4,200	4,180	4,440	4,420
Natural gas	665	663	428	429
Total	4,860	4,840	4,870	4,850
PAD 4 and 5:				
Petroleum and coke	1,200	1,190	1,220	1,220
Natural gas	1,240 r	1,250 r	1,250	1,260
Total	2,440 r	2,440 r	2,470	2,480
Grand total:	8,490 r	8,470 r	8,500	8,490
Of which:				
Petroleum and coke	6,480	6,460	6,750	6,720
Natural gas	2,000 r	2,010 r	1,760	1,770

[r]Revised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes the U.S. Virgin Islands.

TABLE 4

BYPRODUCT SULFURIC ACID PRODUCED IN THE UNITED STATES[1, 2]

(Thousand metric tons of sulfur content and thousand dollars)

Type of plant	2001	2002
Copper[3]	813	695
Zinc[4]	122	50
Lead and molybdenum[4]	47	28
Total:		
Quantity	982	772
Value	$49,500	$35,500

[1]Includes acid produced from imported raw materials.

[2]Data are rounded to no more than three significant digits, may not add to totals shown.

[3]Excludes acid made from pyrites concentrates.

[4]Excludes acid made from native sulfur.

TABLE 5
CONSUMPTION OF SULFUR IN THE UNITED STATES[1, 2, 3]

(Thousand metric tons)

	2001	2002
Elemental sulfur:		
Shipments[4]	8,470 r	8,490
Exports	675	687
Imports	1,730	2,560
Total	9,520 r	10,400
Byproduct sulfuric acid:		
Shipments[4]	982	772
Exports[5]	69	48
Imports[5]	462	346
Grand total	10,900 r	11,400

[r]Revised.

[1]Crude sulfur or sulfur content.

[2]Data are rounded to no more than three significant digits; may not add to totals shown.

[3]Consumption is calculated as shipments minus exports plus imports.

[4]Includes the U.S. Virgin Islands.

[5]May include sulfuric acid other than byproduct.

TABLE 6

SULFUR AND SULFURIC ACID SOLD OR USED IN THE UNITED STATES, BY END USE[1]

(Thousand metric tons of sulfur content)

SIC[3]	End use	Elemental sulfur[2] 2001	Elemental sulfur[2] 2002	Sulfuric acid (sulfur equivalent) 2001	Sulfuric acid (sulfur equivalent) 2002	Total 2001	Total 2002
102	Copper ores	--	--	691	588	691	588
1094	Uranium and vanadium ores	--	--	3	2	3	2
10	Other ores	--	--	26	1	26	1
26, 261	Pulpmills and paper products	--	--	194	122	194	122
28, 285, 286, 2816	Inorganic pigments paints and allied products, industrial organic chemicals, other chemical products[4]	W	--	158	27	158	27
281	Other inorganic chemicals	W	W	207	50	207	50
282, 2822	Synthetic rubber and other plastic materials and synthetics	--	--	68	66	68	66
2823	Cellulosic fibers including rayon	--	--	11	6	11	6
283	Drugs	--	--	3	2	3	2
284	Soaps and detergents	W	W	7	--	7	--
286	Industrial organic chemicals	--	--	86	4	86	4
2873	Nitrogenous fertilizers	--	--	188	105	188	105
2874	Phosphatic fertilizers	--	--	6,840	7,160	6,840	7,160
2879	Pesticides	--	--	10	8	10	8
287	Other agricultural chemicals	1,120	1,650	31	29	1,150	1,680
2892	Explosives	--	--	10	8	10	8
2899	Water-treating compounds	--	--	66	59	66	59
28	Other chemical products	--	--	21	21	21	21
29, 291	Petroleum refining and other petroleum and coal products	1,960	2,390	591	90	2,550	2,480
331	Steel pickling	--	--	17	7	17	7
333	Nonferrous metals	--	--	38	2	38	2
33	Other primary metals	--	--	5	7	5	7
3691	Storage batteries (acid)	--	--	13	3	13	3
	Exported sulfuric acid	--	--	2	334	2	334
	Total identified	3,080	4,040	9,280	8,710	12,400	12,700
	Unidentified	1,750	248	250	52	2,000	300
	Grand total	4,830	4,290	9,530	8,760	14,400	13,000

W Withheld to avoid disclosing company proprietary data; included with "Unidentified." -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Does not include elemental sulfur used for production of sulfuric acid.

[3]Standard Industrial Classification.

[4]No elemental sulfur was used in inorganic pigments and paints and allied products.

TABLE 7
U.S. EXPORTS OF ELEMENTAL SULFUR, BY COUNTRY[1, 2]

(Thousand metric tons and thousand dollars)

Country	2001		2002	
	Quantity	Value	Quantity	Value
Brazil	179	4,570	136	4,270
Canada	52	5,740	50	5,290
China	9	4,510	280	13,700
Korea, Republic of	9	6,920	2	2,240
Mexico	155	7,120	41	2,800
Morocco	75	3,390	156	6,490
Other	196 r	16,500 r	22	5,260
Total	675	48,800	687	40,000

[r]Revised.
[1]Includes exports from the U.S. Virgin Islands.
[2]Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 8

U.S. EXPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY[1]

	2001		2002	
Country	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Canada	159,000	$8,380	129,000	$6,670
China	788	837	525	586
Dominican Republic	531	95	2,540	146
Israel	2,630	818	216	297
Japan	115	159	507	154
Korea, Republic of	59	153	472	154
Mexico	3,240	490	3,080	505
Netherlands	2	9	59	46
Netherlands Antilles	67	63	20	5
Saudi Arabia	2,210	778	1,020	1,170
Singapore	241	207	111	117
Taiwan	485	297	1,470	621
Trinidad and Tobago	6,280	565	1,990	277
United Kingdom	1,860	115	257	83
Venezuela	3	9	--	--
Other	31,900	2,960	6,470	1,930
Total	210,000	15,900	147,000	12,800

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

Source: U.S. Census Bureau.

TABLE 9

U.S. IMPORTS OF ELEMENTAL SULFUR, BY COUNTRY[1]

(Thousand metric tons and thousand dollars)

Country	2001		2002	
	Quantity	Value[2]	Quantity	Value[2]
Canada	1,210	7,060	1,950	9,450
Mexico	359	8,400	430	11,300
Other	161	6,600	180	6,050
Total	1,730	22,100	2,560	26,800

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Declared customs valuation.

Source: U.S. Census Bureau as adjusted by the U.S. Geological Survey.

TABLE 10

U.S. IMPORTS OF SULFURIC ACID (100% H_2SO_4), BY COUNTRY[1]

	2001		2002	
Country	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Canada	525,000	$17,800	615,000	$20,700
Germany	37,100	1,900	99,200	2,970
Japan	47,200	2,510	979	932
Mexico	459,000 r	16,500	97,400	7,900
Spain	41,500	968	10,300	493
Other	305,000 r	11,800	236,000	13,400
Total	1,410,000	51,500	1,060,000	46,400

[r]Revised.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Declared cost, insurance, and freight paid by shipper valuation.

Source: U.S. Census Bureau.

TABLE 11

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

Country and source[3]	1998	1999	2000	2001	2002[e]
Australia, byproduct:[e]					
Metallurgy	507	441	654	817 [r]	899
Petroleum	22	25	30	45	60
Total	529	466	684	862 [r]	959
Canada, byproduct:					
Metallurgy	1,153	1,156	1,167	762 [r]	751 [p]
Natural gas, petroleum, tar sands	8,541	8,960	8,779	8,154 [r]	7,787 [p]
Total	9,694	10,116	9,946	8,916 [r]	8,538 [p]
Chile, byproduct, metallurgy[e]	899	1,040	1,100	1,160	1,275 [4]
China:[e]					
Elemental	230	280	290	290	290
Pyrites	4,490	3,860	3,370	3,090	3,240
Byproduct, metallurgy	1,450	1,630	1,900	2,000	2,200
Total	6,170	5,770	5,560	5,380	5,730
Finland:[e]					
Pyrites	430 [r]	380	377 [r]	337 [r]	340
Byproduct:					
Metallurgy	296 [4]	299	300 [r]	300 [r]	300
Petroleum	40 [r]	42	50 [r]	45 [r]	50
Total	766 [r]	721	727 [r]	682 [r]	690
France, byproduct:[e]					
Natural gas	600	600	600	600	500
Petroleum	245	250	250	250	250
Unspecified	261	250	260	250	250
Total	1,110	1,100	1,110	1,100	1,000
Germany, byproduct:[e]					
Metallurgy	25	25	30	30	30
Natural gas and petroleum	1,100	1,100	1,110	1,110	1,110
Unspecified	50	60	100	100	100
Total	1,180	1,190	1,240	1,240	1,240
India:[e]					
Pyrites	40	32	32	32	35
Byproduct:					
Metallurgy	196	261	359	458	460
Natural gas and petroleum	60	101	376	451	450
Total	296	394	767	941	945
Iran, byproduct:[e]					
Metallurgy	50	47 [r]	50	50	50
Natural gas and petroleum	889	963	963	933	950
Total	939	1,010	1,010	983	1,000
Italy, byproduct:[e]					
Metallurgy	199	193	203	203	142
Petroleum	425	485	490	540	560
Total	624	678 [4]	693 [4]	743	702
Japan:					
Pyrites[e]	23	41	30	30	25
Byproduct:					
Metallurgy	1,322	1,361	1,384	1,319	1,310
Petroleum	2,083	2,060	2,072	2,424 [r]	1,865 [4]
Total	3,428	3,462	3,486	3,773 [r]	3,200
Kazakhstan, byproduct:[e]					
Metallurgy	212	245	300	300	300
Natural gas and petroleum	933	1,070	1,200	1,400	1,800
Total	1,150	1,320	1,500	1,700	2,100
Korea, Republic of, byproduct:[e]					
Metallurgy	476	528	572	665	670
Petroleum	600	600	600	600	610
Total	1,080	1,130	1,170	1,270	1,280
Kuwait, byproduct, natural gas and petroleum[e]	650	639	512	524	634

See footnotes at end of table.

TABLE 11--Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

Country and source[3]	1998	1999	2000	2001	2002[e]
Mexico, byproduct:					
Metallurgy	474	474	474	572 [e]	575
Natural gas and petroleum	913	860	851	878	875
Total	1,387	1,334	1,325	1,450	1,450
Netherlands, byproduct:[e]					
Metallurgy	131	129	123	126	124
Petroleum	432	445	428 [4]	384	373
Total	563	574	551	510	497
Poland:[5]					
Frasch	1,345	1,172	1,482	942 [r]	760 [4]
Byproduct:					
Metallurgy	260 [e]	278	279 [r]	277 [r]	275
Petroleum	60	74 [e]	70 [e]	133 [r]	180 [4]
Gypsum[e]	10	--	--	--	--
Total	1,675	1,524	1,831 [r]	1,352 [r]	1,220
Russia:[e, 6]					
Native	50	50	50	50	50
Pyrites	254	300	350	400	400
Byproduct, natural gas	3,936 [4]	4,405 [4]	4,900	5,300	5,400
Other	411	510	600	500	500
Total	4,651 [4]	5,265 [4]	5,900	6,250	6,350
Saudi Arabia, byproduct, all sources	2,050	1,940	2,101	2,350 [e]	2,230
Spain:					
Pyrites	430	388	138	71 [e]	--
Byproduct:[e]					
Coal (lignite) gasification	2	2	1	1	1
Metallurgy	461	455	454	461 [r]	544
Petroleum	100	110	115	135 [r]	140
Total	993	955	708	668 [r]	685
United Arab Emirates, byproduct, natural gas and petroleum[e]	967	1,089 [4]	1,120	1,490	1,900
United States:					
Frasch[e]	1,800	1,780	900	-- [4]	-- [4]
Byproduct:					
Metallurgy	1,610	1,320	1,030	982	772 [4]
Natural gas	2,240 [r]	2,150 [r]	2,230 [r]	2,000 [r]	1,760 [4]
Petroleum	6,060	6,210	6,360	6,480	6,750 [4]
Total	11,700 [r]	11,500 [r]	10,500 [r]	9,470 [r]	9,270 [4]
Other:[e, 7]					
Frasch	25 [r]	23 [r]	24 [r]	24 [r]	25
Native	417 [r]	285 [r]	288 [r]	259 [r]	256
Pyrites	305 [r]	280 [r]	254 [r]	299 [r]	283
Byproduct:					
Metallurgy	938 [r]	914 [r]	949 [r]	1,110 [r]	1,130
Natural gas	206	215	256 [r]	281 [r]	281
Natural gas, petroleum, tar sands, undifferentiated	862 [r]	445 [r]	724 [r]	730 [r]	661
Petroleum	938 [r]	869 [r]	966 [r]	911 [r]	937
Unspecified	1,350 [r]	1,310 [r]	1,410 [r]	1,430 [r]	1,380
Total	5,040 [r]	4,340 [r]	4,870 [r]	5,040 [r]	4,950

See footnotes at end of table.

TABLE 11--Continued

SULFUR: WORLD PRODUCTION IN ALL FORMS, BY COUNTRY AND SOURCE[1, 2]

(Thousand metric tons)

Country and source[3]	1998	1999	2000	2001	2002[e]
Grand total:	57,400 r	57,400 r	58,300 r	57,700 r	57,700
Of which:					
Frasch	3,170	2,980	2,410	966 r	785
Native[8]	697 r	615 r	628 r	599 r	596
Pyrites	5,970 r	5,280 r	4,550 r	4,260 r	4,320
Byproduct:					
Coal, lignite, gasification[e]	2	2	1	1	1
Metallurgy	10,700	10,800	11,300	11,600	11,800
Natural gas	6,980 r	7,370 r	7,980 r	8,180 r	7,940
Natural gas, petroleum, tar sands, undifferentiated	14,900	15,200 r	15,600 r	15,700 r	16,200
Petroleum	10,900 r	11,100 r	11,300 r	11,800 r	11,600
Unspecified	4,120 r	4,070 r	4,470 r	4,630 r	4,460
Gypsum[e]	10	--	--	--	--

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

[1]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through July 22, 2003.

[3]The term "Source" reflects the means of collecting sulfur and the type of raw material. Sources listed include the following: Frasch recovery; native comprising all production of elemental sulfur by traditional mining methods (thereby excluding Frasch); pyrites (whether or not the sulfur is recovered in the elemental form or as acid); byproduct recovery, either as elemental sulfur or as sulfur compounds from coal gasification, metallurgical operations including associated coal processing crude oil and natural gas extraction, petroleum refining, tar sand cleaning, and processing of spent oxide from stack-gas scrubbers; and recovery from processing mined gypsum. Recovery of sulfur in the form of sulfuric acid from artificial gypsum produced as a byproduct of phosphatic fertilizer production is excluded, because to include it would result in double counting. Production of Frasch sulfur, other native sulfur, pyrite-derived sulfur, mined gypsum derived sulfur, byproduct sulfur from extraction of crude oil and natural gas, and recovery from tar sands are all credited to the country of origin of the extracted raw materials. In contrast byproduct recovery from metallurgical operations, petroleum refinieries, and spent oxides are credited to the nation where the recovery takes place, which is not the original source country of the crude product from which the sulfur is extracted.

[4]Reported figure.

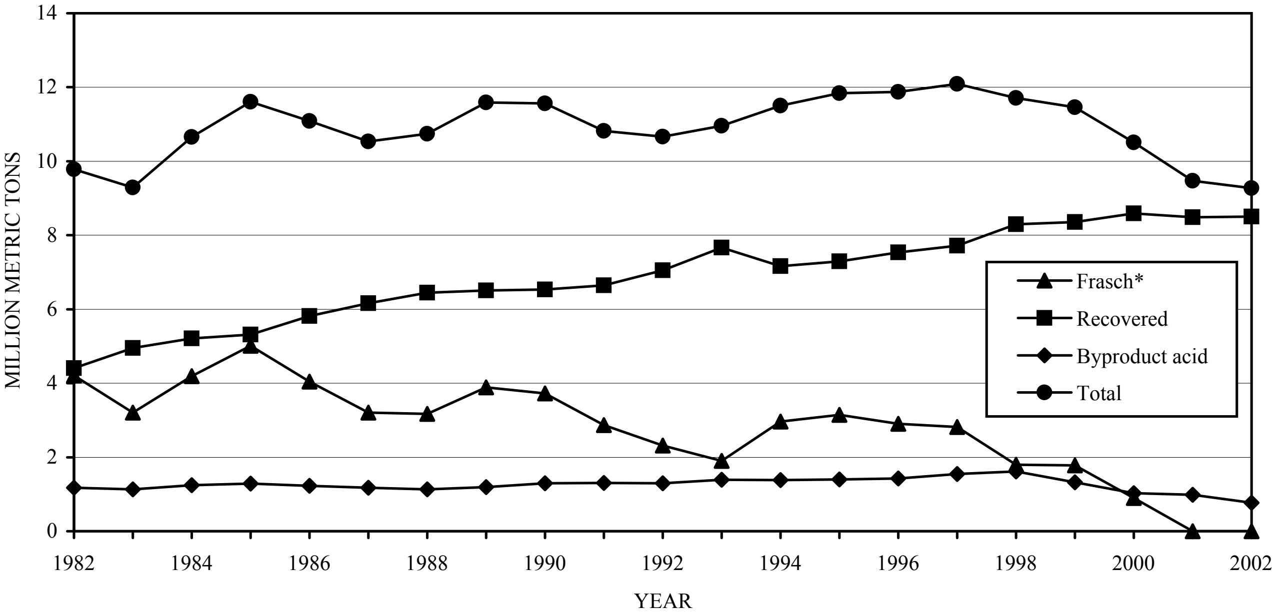
[5]Official Polish sources report total Frasch and native mined elemental sulfur output annually, undifferentiated; this figure has been divided between Frasch and other native sulfur on the basis of information obtained from supplementary sources.

[6]Sulfur is believed to be produced from Frasch and as a petroleum byproduct; however, information is inadequate to formulate estimates.

[7]"Other" includes Albania, Algeria, Aruba, Austria, Bahrain, Belarus, Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Colombia, Croatia, Cuba, the Czech Republic, Denmark, Ecuador, Egypt, Greece, Hungary, Indonesia, Iraq, Israel, North Korea, Kuwait, Libya, Macedonia, Namibia, the Netherlands Antilles, Norway, Oman, Pakistan, Peru, Philippines, Portugal, Qatar, Romania, Serbia and Montenegro, Singapore, Slovakia, South Africa, Sweden, Switzerland, Syria, Taiwan Trinidad and Tobago, Turkey, Turkmenistan, Ukraine, the United Kingdom, Uruguay, Uzbekistan, Venezuela, Zambia, and Zimbabwe.

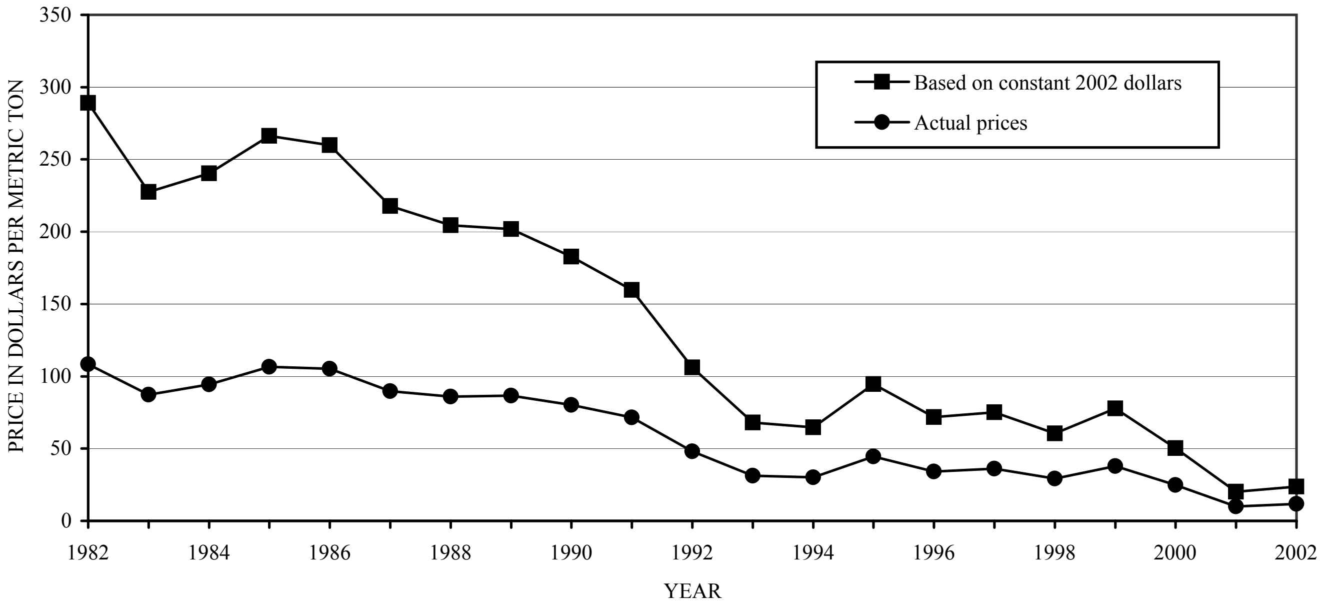
[8]Includes "China, elemental."

FIGURE 1
TRENDS IN SULFUR PRODUCTION IN THE UNITED STATES



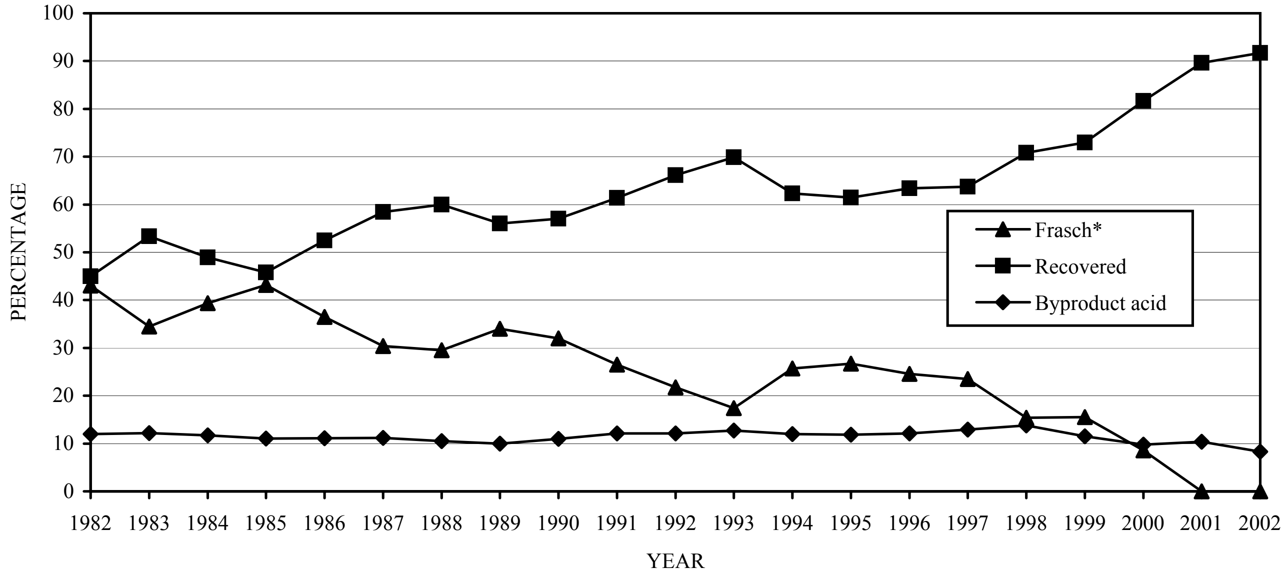
*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to conform with proprietary data requirements. Data are estimates for 1994 through 2000.

FIGURE 2
ESTIMATED AVERAGE PRICE OF SULFUR IN ACTUAL AND CONSTANT DOLLARS



Based on the average reported value for elemental sulfur (Frasch and recovered), free on board mine and/or plant.

FIGURE 3
PERCENTAGE OF SULFUR PRODUCTION BY SOURCE



*Includes 10 months of Frasch data for 1993; the other 2 months are included with the recovered sulfur data to conform with proprietary data requirements. Data are estimates for 1994 through 2000.

FIGURE 4
TRENDS IN SALIENT SULFUR STATISTICS